Inherent Optical Properties in the Benthic Environment

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LONG-TERM GOALS

The long term goals of this effort are to delineate the small scale structure of the inherent optical properties (IOP) in the benthic environment as a function of substrate and biogeochemical and physical processes. In addition we would like to determine how small scale variations in the IOP affect radiative transfer and visibility in the benthic environment.

OBJECTIVES

1. Determine the small scale structure of the IOP and spectral fluorescence in benthic regimes. The structure is expected to be different for different IOP.
2. Determine what particulate and dissolved material properties cause the observed variations in the IOP or fluorescence. Can the IOP be inverted to give cm scale distributions of particulate and dissolved material properties? Can sources of dissolved and suspended materials be identified?
3. Determine how the small scale variations in the IOP affect radiative transfer and visibility in benthic environments.

APPROACH

During the Coastal Benthic Optical Properties (CoBOP) field program we have used the diver operated spectral absorption and attenuation meter (ac-9) and a spectral fluorometer (SAFIRE) developed by us in collaboration with Western Environmental Technology Laboratories (WET Labs) to measure the spectral absorption and attenuation coefficients on small scales within coral reefs, seagrass beds and other benthic environments (Zaneveld et al.,2001). Last year we added a CTD (SeaBird microcat) to the diving package. We also used a sampling package for profiled and moored applications which included two ac-9's (one for use with a 0.2 μm pore size filter) to determine the temporal distribution of IOP on scales of 0.1-2 hrs as part of the closure experiment.

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14. ABSTRACT
The long term goals of this effort are to delineate the small scale structure of the inherent optical properties (IOP) in the benthic environment as a function of substrate and biogeochemical and physical processes. In addition we would like to determine how small scale variations in the IOP affect radiative transfer and visibility in the benthic environment.

15. SUBJECT TERMS

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Calibration was obtained using a Barnstead water purifier. The IOP measured were the spectral absorption and attenuation coefficients, with the spectral scattering coefficient obtained as a derived parameter. A 0.2 μm pre-filter was used at times to distinguish between IOP of the dissolved and particulate fractions. Data were collected and stored via an enclosed data-logger. The underwater package also contained a battery pack and pump. Water was sucked into the ac-9 via a tube held by the diver. Wavelengths used were 412, 440, 488, 510, 532, 555, 650, 676, and 715 nm. A second diver used a video camera to record the diver with the ac-9 package and/or log the details of the dive. Coordination of the times on the recorder and the video camera thus allow the determination of the IOP spectra over specific substrates. We added a hard plastic suction tube to the end of the water intake. This allowed us to insert the tube into the sediment and to sample pore water optical properties at various depths in the sediment. Drs. Zaneveld and Boss together with Mr. Washburn carried out the field program.

WORK COMPLETED

During the last 12 months we have carried out analyses of the field data in order to meet the objectives. We published one paper (Zaneveld et al. 2001) on the technical aspects of the diver -operated package in the Journal of Atmospheric and Oceanic Technology. We have submitted a manuscript to Limnology and Oceanography that covers the results of our analyses (Boss and Zaneveld, 2001).

RESULTS

The measurements described here were obtained in areas adjacent to Lee Stocking Island (LSI), Bahamas. Observations were made at several sites to the West (Exuma Sound) side of LSI and at several sites on the shallow Eastern side of LSI. We reference depth to the bottom, as this is the primary length of importance when dealing with benthic processes. The results described here span 3 sampling periods, spring 1999, winter 2000, and spring 2000. Each sampling period lasted nearly two weeks.

Since the optical properties at different wavelengths are not independent we concentrate here on a fraction of the optical measurements. Measured properties that were used to infer biogeochemical parameters were: $a_g(440)$ (or $c_g(440)$)– denotes the absorption by colored dissolved material (CDM) ; and $c_{pg}(650)$ – indicator of total suspended particulate mass (volume or concentration, e.g. Spinrad et al., 1983) (CDM absorption at this wavelength is negligible).
Derived properties were: [chl] = $[a_{pg}(676)-a_{pg}(650)]/0.014$ – indicator of chlorophyll a concentration (in μg/liter) which in turn is an indicator, at a given light level, of phytoplankton biomass; γ – slope of c_p, indicator of tendencies of the particulate size distribution (Boss et al., 2001a and Boss et al., 2001b) ; s – slope of a_g, indicator of CDM "flavor". A steep slope (~0.02) represents "fulvic"-like or low molecular weight material while a flatter slope (~0.01) represents "humic"-like or high molecular weight (Carder et al., 1989, Blough and Del Vecchio, 2002).

The current velocity field at several sites were monitored by Dr. Rob Wheatcroft (unpublished data). At North Perry, a site on the Exuma Sound side of LSI, the largest velocity was along the reef, following the bathymetry. Across reef velocities had a mean absolute velocity of 0.2cm/sec, a standard deviation of 3.5cm/sec, and a maximal velocity of 20cm/sec. Thus, at most times there was little exchange of water between reef and sand flats, except for short episodic exchanges, probably associated with stresses due to large swells (whose direction was often across the reef/sand boundary). To the West of LSI, over the Bahama banks, tidal velocities were O(40cm/sec). These tended to homogenize the waters over the shallow banks.

Results from transects performed at 10cm, 50cm, 100cm and 200cm depth from the reef to the adjacent sand flats at three different sites on the Exuma Sound side of LSI were analyzed. An example of a record of such a transect is presented in Fig. 1.

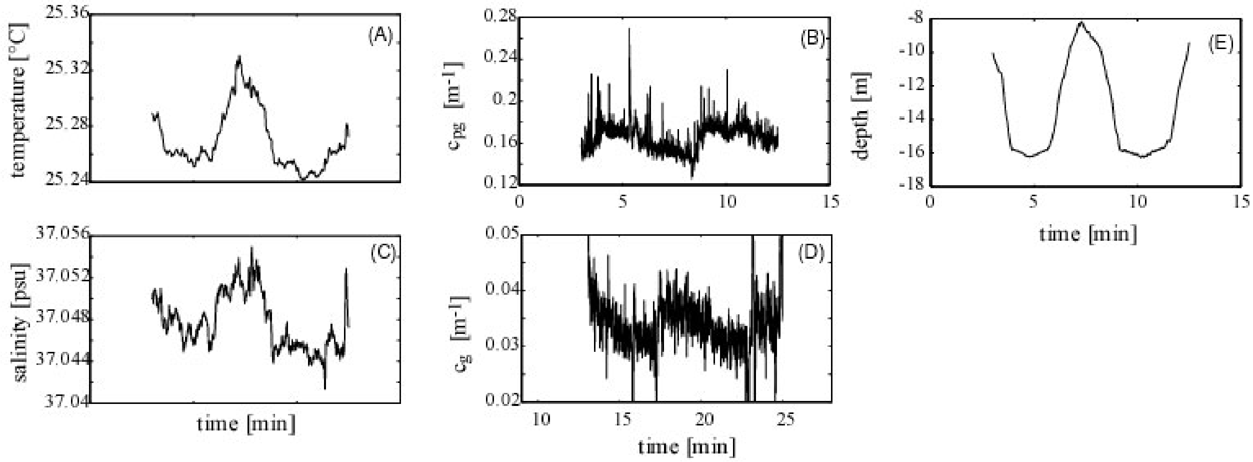

Figure 1. Transect
[graph: variability of temperature, total beam attenuation, salinity, attenuation of dissolved materials and depth as a function of time for a transect within 10 cm of the bottom.]

Results can be summarized as follows:
1. The variability in all properties was larger over the reef and variability in all properties was larger at 10cm above both reef and sand than further from the bottom. Processes associated with the bottom substrate create larger variability in particulate and dissolved properties relative to higher up in the upper column consistent with biogeochemical processes associated with the substrate being sources or sinks for particulate and dissolved material. Variability is higher over the reef, most likely due to the heterogeneity of the reef in both topography and organisms relative to the sand flat.

2. CDM concentration was larger over the reef. CDM spectral slope was smaller over the reef. CDM concentration was larger at 10cm above the bottom than further from the bottom. CDM spectral slope was smaller at 10cm above both reef and sand. We thus find reefs and seagrass beds to be sources of dissolved material. This CDM pattern is likely to be due to release of metabolites from sponges and corals and/or byproducts of primary production by the micro-algae on the reef. Dense sea-grass beds are associated with large mats of decomposing dead leaves, which are likely to be the major source of the CDM released over the bank. Reefs-released CDM has a lower spectral slope relative to the water column above it. Seagrass beds release CDM with higher spectral slope than the Exuma Sound waters (Fig. 2), though relatively low compared to coastal CDM (where *s*~0.015, Roesler et al., 1989). Low spectral slope is characteristic of humic substances which have relatively high molecular weight (Carder et al., 1989, Blough and Del Vecchio, 2002).

3. Attenuation was larger over sand but its spectral slope was larger over the reef. Attenuation increased above the reef, while above sand the change in concentration was not significant. Attenuation

spectral slope decreased with increasing distance from both sand and reef substrate. The particulate attenuation decrease towards the bottom is associated with *steepening* of the attenuation spectral slope, suggesting that near the substrate there is removal of the relatively bigger particles compared to higher up in the water column. This gradient has the opposite sign of the gradient in attenuation spectral slope observed when particulates are resuspended (Boss et al., 2001a); Resuspension and sinking of particulate material result in *flattening* of the attenuation spectral slope towards the bottom. Even above the sand flat we see steepening of the spectral slope towards the bottom suggesting that benthic organisms within the sand filter out particles from the water adjacent to the substrate.

4. In most cases [chl] was larger over sand. [chl] increased away from substrate.

5. The mean of a given measured property was, in general, higher than its median. It can be shown that in a heterogeneous environment, such as the near bottom environment, a sensor will be affected by the mean of the optical properties of the medium (rather than the median or mode). We found that, near the bottom, the mean of attenuation can be tens of percent larger than the median, implying the importance of sampling at scales which encompass the local variability. Near-bottom optical properties and their variability are important inputs into radiative-transfer models describing light propagation in the coastal ocean. Imaging of bottom structures, flora and fauna depends on the near bottom optical properties. Our results suggest that near bottom variability in IOPs is usually small, though significant. The mean attenuation coefficient in the blue could vary by 50% between reef and sand (see also Fig. 4 of Zaneveld et al., 2001). However as one extends further up in the water column the differences diminish, consistent with the sources of variability being close to the substrate.

6. In contrast to the gradients observed on the Exuma Sound side of LSI, over the banks we did not measure horizontal and vertical gradients in optical properties that were larger than the local temporal gradients over scales of minutes. We believe that this contrast is due to the contrast in current velocities (and hence mixing), which were much larger over the banks.

7. Using a rigid attachment to the water intake of our device (see Zaneveld et al., 2001) we measured the CDM absorption within and above the sediment in three different types of sediment all located within 150m of each other near Channel Marker, a shallow site to the West (Bahama Bank) side of LSI. During flood tide we found all bottoms, varying from dense grass beds to sparse grass beds to barren carbonate sediments comprised of ooids, to have higher CDM absorption than the overlying waters. During ebb tide, the barren ooids bottom was the only type to have less CDM absorption than the overlying waters. No significant differences were found in CDM spectral slope across the sediment water interface. We observe that grass covered sediment to be sources of CDM to the water column and that ooids sediment (which are poor in organic content) have a CDM gradient across the sediment water interface that depends on the phase of the tide. This reversal suggests that the CDM absorption in the ooids is due to slow diffusional flux into and out of the sediment while the grass covered sediments are sources of CDM.

8.A time series in hydrographic and optical properties was obtained at the Rainbow South site (RS) during May 20-12, 2000 at 50cm above the bottom (average depth, 3m). RS is a tidally flushed channel connecting the banks with Exuma Sound. Fluxes of CDM were mostly negative (Fig. 2D) implying the banks were, on average, exporting CDM to the sound. CDM concentration, its spectral slope and the water salinity were higher over the bank water relative to Exuma water (Fig 2). Correlation between salinity and CDM was high (R^2=0.95) and positive (Fig 2E). Since more evaporation occurs over the banks, the correlation of salinity and CDM absorption is positive, in contrast to the negative correlation found between salinity and CDM in coastal waters affected by fluvial inputs (e.g. Blough and Del Vecchio, 2002). Fluxes of CDM absorption from sediment to the water column were hypothesized to occur over the continental shelf (Boss et al., 2001c) and have been observed here.

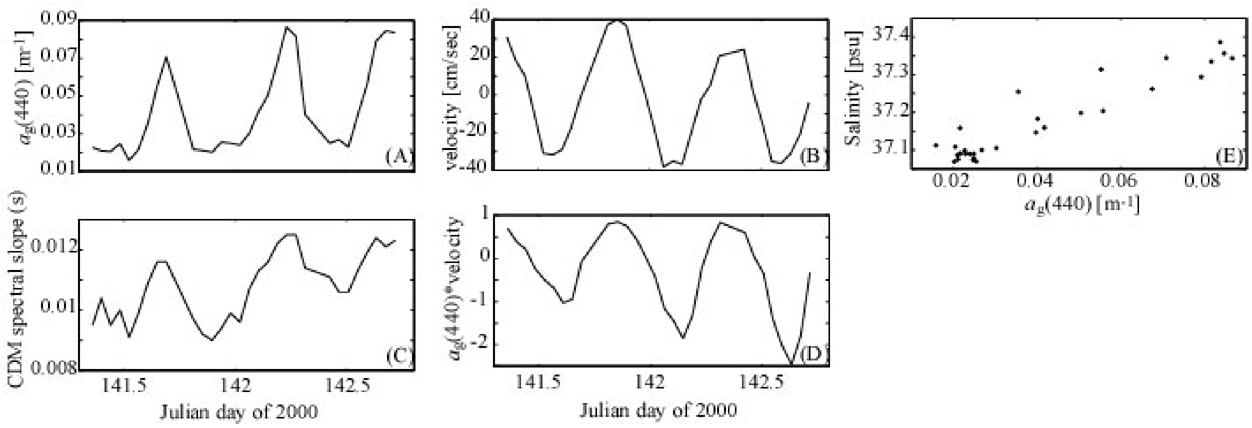

Figure 2, Once an hour time series at Rainbow South.
[graph: CDM absorption (A); spectral slope (B); across bank velocity (C) and across bank CDM absorption flux per unit area (D); Salinity-CDM absorption relationship is depicted in (E).]

IMPACT/APPLICATIONS

We have provided a method for the measurement of small scale horizontal variability of optical and physical parameters in the benthic environment. We have shown that the gradients in IOP reflect the metabolic processes associated with a coral reef. A major application of this data is to test the plane parallel assumption often used in radiative transfer i.e. it is assumed that IOP do not vary horizontally. Our measurements show that the IOP above coral reefs are not homogeneous horizontally or vertically (Fig. 2). We have pioneered a new method of measuring pore-water CDOM absorption and physical properties in-situ.

TRANSITIONS

Our data are being used by Drs. Philpot, Mobley, Reid, Maffione, Zimmerman, and Lesser as inputs into radiative transfer models. Dr Burdige uses our pore-water CDOM measurement for comparison with his laboratory measurements of DOC. The data are available on our web site (http://photon.oce.orst.edu/ocean/projects/cobop/cobop.htm). The data have been submitted to Dr. Jeff Smart for inclusion in the ONR Optics data base.

RELATED PROJECTS

None

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PATENTS

None.